Dynamic Modeling of Marine Bioluminescence and Night Time Leaving Radiance

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LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant physical-biological dynamics in shallow coastal environments.

OBJECTIVES

Our objectives are to develop the methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days, and to understand the coupled bio-optical and physical processes in the coastal zone that governs the variability and predictability of bioluminescence.

APPROACH

Approach is based on joint studies of the marine bioluminescence potential (BL) and Inherent Optical Properties (IOPs) over relevant time and space scales, combining recent advances in the bioluminescence research: a novel approach for distinguishing relative abundances of planktonic dinoflagellates and zooplankton (Moline et al., 2009), modeling of nighttime leaving radiance and

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bioluminescence inversion (Moline et al., 2007 and Oliver et al., 2007) and development of a methodology for short-term bioluminescence predictions (Shulman et al., 2003 and 2005). The proposed research is being significantly leveraged by the interdisciplinary and multi-institutional modeling and field efforts of the NRL BIOSPACE and MURI ESPRESSO projects. Bio-optical, physical observations from the following field programs are being used in this study: AOSN I and II (Moline, 2007 and 2009, Shulman et al., 2003, 2005, 2009); bioluminescence observations from Monterey Bay surveys conducted by Dr. Haddock (Augusts of 2000, 2002, Decembers of 2002 and 2003 and March of 2004); NRL BIOSPACE-ESPRESSO May-June of 2008 experiment; NRL BIOSPACE/MBARI CANON experiment in October 2010.

WORK COMPLETED

Dynamical, predictive biochemical, physical and bioluminescence intensity models are combined into a methodology for estimating the nighttime water-leaving radiance due to stimulated bioluminescence at depth.

The methodology is tested in simulation of observed bio-optical (including bioluminescence) and physical dynamics during the upwelling event. During the development of upwelling in the Monterey Bay area, the observed offshore water masses (in the area around mooring M1 at the entrance to the Bay) with the subsurface layer of bioluminescent zooplankton were replaced by water masses with a relatively high presence of mostly non-bioluminescent phytoplankton, which was advected from the northern coast of the bay. The bioluminescent dinoflagellates from the northern part of the Bay were able to avoid advection by southward flowing currents along the entrance to the Monterey Bay into the M1 area, while non-bioluminescent phytoplankton was advected. We have evaluated a hypothesis regarding whether modeling dinoflagellates dynamics with introduced vertical swimming behavior can explain the observed dinoflagellates' avoidance to be advected by strong currents.

Paper describing results is published in JGR Oceans.

Another paper is submitted to JGR Oceans.

RESULTS

In the Monterey Bay area, during upwelling, typically strong southward flowing jet along the entrance to the bay develops, this jet separates cyclonic circulation inside of the Bay and antycyclonic outside the Bay as it is shown in HF Radar derived surface currents (Figure 1). This jet penetrates up to 150m depth. Inshore AUV observations in the Upwelling Shadow Area (Figure 1, noted by SA) show consistent coincidence of chlorophyll, backscatter, and bioluminescence maxima during upwelling development. At the beginning of the upwelling, Offshore AUV observations (around mooring M1 location) show deeper bioluminescence maxima below the surface layers of high chlorophyll and backscatter values (Figure 1, August 11th). The inshore BL maxima are associated with phytoplankton (dinoflagellates), while offshore BL maxima are due to larger zooplankton. During the upwelling development (Figure 1, August 15th), the observed offshore water masses with the subsurface layer of bioluminescent zooplankton were replaced by water masses with a relatively high presence of mostly non-bioluminescent phytoplankton (mooring M1 area, August 15th, high values of chlorophyll but low values of bioluminescence potential). This non-bioluminescent phytoplankton was advected from the northern coast of the bay. The bioluminescent dinoflagellates from the northern part of the Bay were able to avoid advection by southward flowing currents along the entrance to the Monterey Bay into the

M1 area, while non-bioluminescent phytoplankton was advected (Figure 1). It is known (for example, see Smayada, 2010) that vertical swimming of dinoflagellates to deeper layers helps them avoid losses due to advection. We have evaluated a hypothesis regarding whether modeling dinoflagellates dynamics with introduced vertical swimming behavior can explain the observed dinoflagellates' avoidance to be advected by strong currents (Shulman et al, 2011a). The dynamics of dinoflagellates is modeled with the tracer model where the dinoflagellate population is modeled as a concentration, and vertical swimming velocity is introduced into the tracer advective-diffusive-reaction model. Three swimming behaviors were considered: sinking, swimming to the target depth and diel vertical migration. Swimming velocities in all cases were considered in the range of documented velocities for the dinoflagellates species observed during the upwelling development in the Monterey Bay.

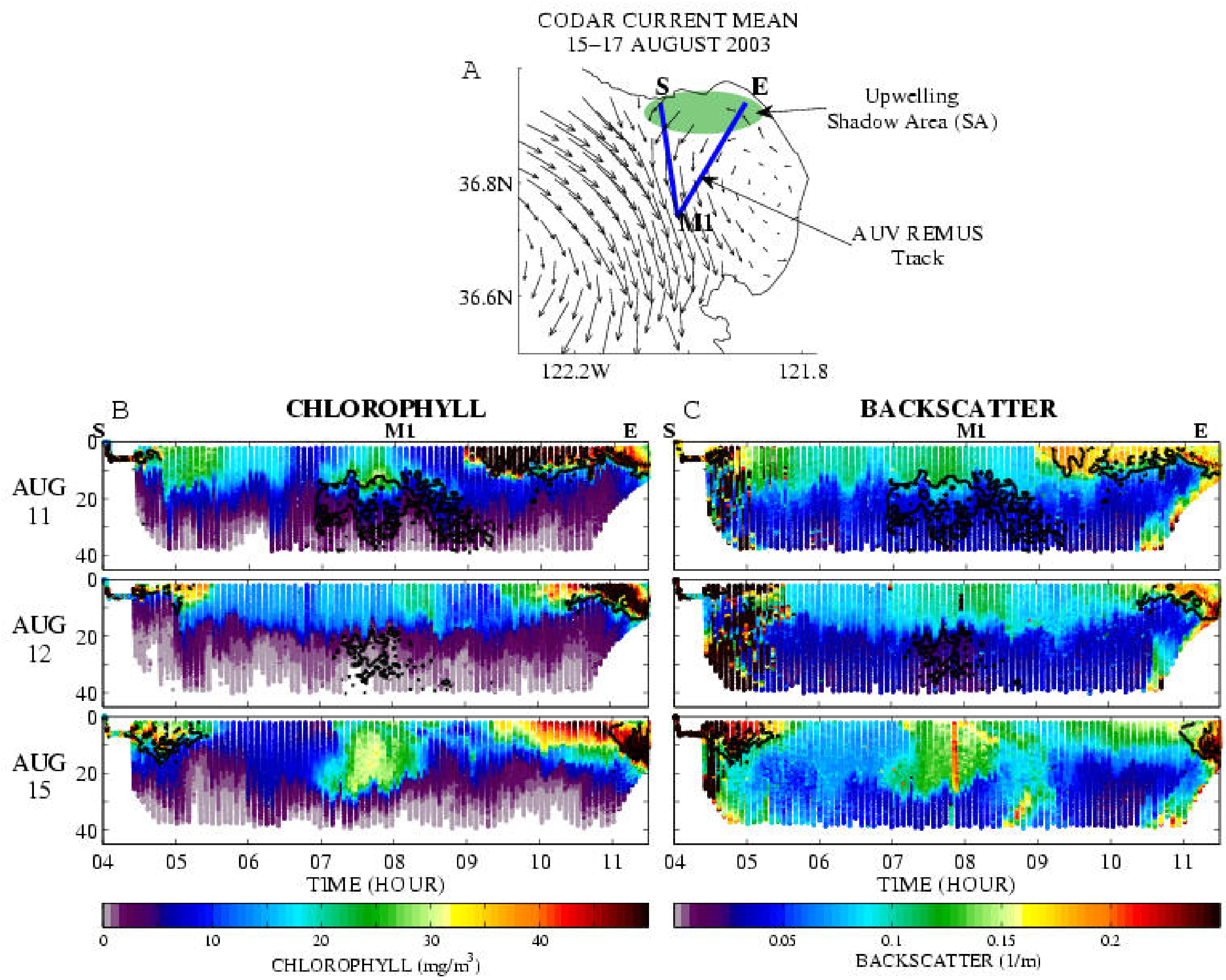

Figure1. (A) HF radar surface currents averaged over 3 days of upwelling (15-17 August of 2003). (B) AUV Remus observed chlorophyll with bioluminescence potential maxima overlay (black contours).(C) AUV Remus observed backscattering with bioluminescence potential maxima overlay (black contours). Bioluminescence potential maxima contours are plotted in the log $_{10}$ scale in range (10.4, 11.2).

Using the adjoint to the tracer model, we showed that with swimming at a speed 20m/day (which is in the middle of the swimming velocities ranges for observed dinoflagellates species), approximately 40% of tracer concentration from the northern part of the Bay will be advected in comparison to the case without swimming. This is in agreement with the observed ratio of mean bioluminescence potential BL intensity in the northern part of the Bay to the BL intensity at the M1 location (Table 1) which is ~45% on August 15th of 2003.

Table 1. Observed mean bioluminescence potential in Upwelling Shadow Area (SA) and at M1 (x10^{10} photon/sec).

	Observed		
	SA	M1	M1/SA (%)
15 Aug.	3.07	1.39	45
16 Aug.	3.37	0.62	18
17 Aug.	4.23	0.35	8

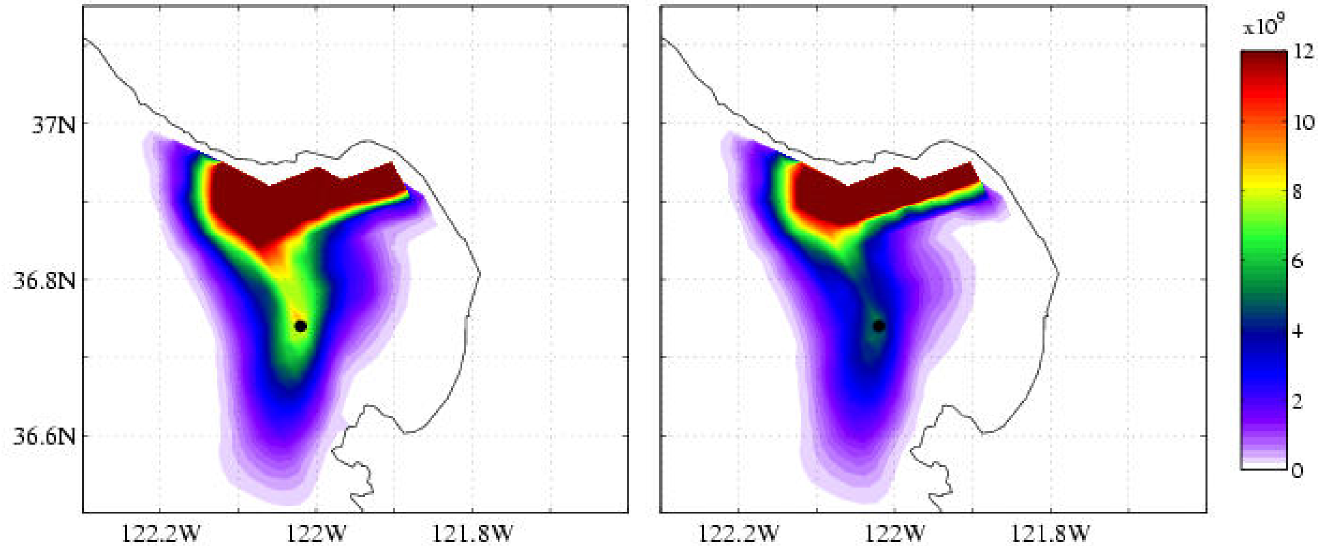

Figure 2. Vertically integrated (up to 25m depth) concentrations maps for 24 hours of forward simulations at August 15th of 2003. On the left for the model run without introduced vertical swimming, and on the right, for the model run with introduced diel vertical migration with the speed 20 m/day. Location of mooring M1 is marked by black dot.

Therefore, dinoflagellates swimming with the speed around the middle of the observed range of swimming velocities could avoid advection to the area around mooring M1 during the upwelling development. To further verify our results from the adjoint runs, we conducted forward simulations with the tracer model. In forward simulations, we used the initial distribution of BL (derived in Shulman et al., 2011b) as proxy for the initial distribution of dinoflagellates in the northern part of the Bay. It is shown that with a swimming velocity of 20m/day, about 50% less of the dinoflagellates population is advected from the shadow area to the area around M1, in comparison to the case with no swimming (Figure 2). This is in agreement with results from adjoint runs and again explains the observed 45% ratio of BL intensities between the northern part of the Bay and the area around the mooring M1. The mechanism for dinoflagellate retention in northern Monterey Bay presented here is also consistent with the observed seasonal persistence of dinoflagellates (Ryan et al. 2005, 2009).

Therefore, our modeling studies have demonstrated that the observed dinoflagellates' avoidance of advection by the southward flowing jet along the entrance to the Bay can be explained by the dinoflagellates' ability to swim vertically. This complicates even short-term (1 day) modeling and predictions of underwater light, BL and water leaving radiances. Examples presented here and in Shulman et al, 2011a,b demonstrate that advective processes might identify plankton aggregations, but do not accurately predict even shot-term changes (1 day) in horizontal and vertical redistributions of these populations, especially in cases when plankton swimming behavior is involved.

IMPACT/APPLICATIONS

Prediction of the location, timing and intensity of bioluminescence potential is critical for numerous naval operations including preventing detection of covert operations involving submarines, Swimmer Delivery Vehicles and AUVs, as well as in aiding detection of enemy incursions. At present, the Navy does not have capability to forecast BP potential and night time water leaving radiance. The proposed research aims to develop a methodology for bioluminescence potential and bioluminescence leaving radiance predictions on scales to 1-5 days.

TRANSITIONS

None.

RELATED PROJECTS

NRL, RO " Bio-Optical Studies of Predictability and Assimilation for the Coastal Environment (BIOSPACE)" (PI: I. Shulman)

I. Shulman is PI of the NRL project with objectives to improve understanding of the variability and predictability of the underwater light and bio-optical, physical properties on time scales of 1 to 5 days. NRL coupled models and predictions of physical bio-optical properties (including IOPs and BP) are used in our project.

The Multidisciplinary University Research Initiative (MURI) project "Rapid Environmental Assessment Using an Integrated Coastal Ocean Observation-Modeling System (ESPRESSO)"

(PIs: O. Schofield, S. Glenn, J.Wilkin, G. Gawarkiewicz, R. He, D. McGillicuddy, K. Fennel, M. Moline).

Objectives of the MURI project are focused on the development of a data assimilative physical-optical modeling-observation system capable of improving predictive skill for forecasting ocean color and improving physical models by using ocean color. M. Moline is Co-PI of the project, and NRL BIOSPACE and MURI project have similar objectives and there are ongoing collaborations between projects.

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PUBLICATIONS

Shulman, I., M. A. Moline, B. Penta, S. Anderson, M. Oliver, and S. H. D. Haddock (2011), Observed and modeled bio-optical, bioluminescent, and physical properties during a coastal upwelling event in Monterey Bay, California, J. Geophys. Res., 116, C01018, doi:10.1029/2010JC006525.

HONORS/AWARDS/PRIZES

Dr. Mark Moline received Fulbright Distinguished Arctic Chair Award.